Variation of Internal Friction with Magnetization in Nickel

著者	TANJI Yasunori, SHIRAKAWA Yuki, MORIYA Hiroshi
journal or publication title	Science reports of the Research Institutes, Tohoku University. Ser. A, Physics, chemistry and metallurgy
volume	21
page range	250-259
year	1969
URL	http://hdl.handle.net/10097/27507

Variation of Internal Friction with Magnetization in Nickel*

Yasunori TANJI, Yûki SHIRAKAWA and Hiroshi MORIYA

The Research Institute for Iron, Steel and Other Metals

(Received January 24, 1970)

Synopsis

The internal friction Q^{-1} of nickel annealed at 1000°C for 10 hr was measured in a magnetic field by the electrostatic driving method. The results obtained are as follows: (1) With decreasing magnetic field H from a magnetically saturated state, Q^{-1} increases from about $H=30$ Oe and shows a maximum at $H=15$ Oe. (2) The magnetic hysteresis loss Q_h^{-1} was separated from the whole Q^{-1} through measurement of the dynamic stress with an interference comparameter. (3) When Q_h^{-1} is expressed as a function of magentization I/I_s, Q_h^{-1} shows a maximum at $I/I_s=0.6$; it becomes smaller with increasing driving frequency f and vanishes at $f=5.8$ kHz.

I. Introduction

In the previous reports,[1][2] the dynamic ΔE effect of nickel has been measured and it has been found that ΔE curves in weak magnetic fields show a remarkable variation with driving frequencies. That is to say, at a low frequency such as 0.64 kHz, the Young's modulus of nickel decreases at first with increasing magnetic field and, after passing a minimum, turns to increase and finally shows a state of saturation. The formation of this minimum lies shallower with increasing driving frequency, and vanishes at 5.80 kHz. However, the mechanism of frequency dependence is so complicated that it is extremely difficult to confirm it quantitatively where the domain structure remains uncertain. The present authors, therefore, have studied it qualitatively.

On the assumption that the dynamic ΔE effect of ferromagnetic bodies consists of the effect of a change in the magnetic domain distribution due to magnetic field or elastic stress and that of a fixation of magnetic domain due to the magnetic viscosity of eddy currents generated on vibration frequencies, the magnetic elongation ε_m was shown as follows:

$$\frac{d\varepsilon_m}{d\sigma}=\frac{d\varepsilon_H}{d\sigma}+\frac{d\varepsilon_f}{d\sigma} \tag{1}$$

where $d\varepsilon_H$ denotes the elongation due to magnetostriction, and $d\varepsilon_f$ the elongation due to such force as has arisen from the difference between dynamic stress and

* The **1444th** report of the Research Institute for Iron, Steel and Other Metals. Published in the J. Japan Inst. Metals, **33** (1969), 1354 (in Japanese).

(1) Y. Shirakawa and Y. Tanji, J. Phys. Soc. Japan, **23** (1967), 908.

(2) Y. Shirakawa and Y. Tanji, J. Japan Inst. Metals, **33** (1969), 819.

magnetic viscoisty. The second term of Eq. (1), as shown in the preceding report,[2] is represented as a function of differential susceptibility $\chi_r(f)$, so the effect can also be expected to appear in the same way as the ΔE effect in the internal friction. Therefore, those specimens used in the measurement of Young's moduli were adopted again in the current measurement of the internal friction.

II. Specimens and measurements

The specimens used were, just as those used in the measurement of Young's moduli, flat rectangular bars of nickel annealed in vacuum at 1000°C for 10 hr, each 100.10 mm in length, 10.05 mm in width, and 1.326 mm in thickness. The demagnetization factor of the specimen is $N=0.00485$.

The electrostatic driving method was used for measurement of resonance curves on the fundamental, second, third and fourth modes of resonance, and the internal friction Q^{-1} was obtained from the following equation:

$$Q^{-1}=\frac{1}{\sqrt{3}}\cdot\frac{\Delta f}{f_0} \tag{2}$$

where f_0 is resonance frequency, and Δf half the width of f_0. The measurements were carried out at room temperature in vacuum, and the vibration stress was calculated[3] after the largest amplitude between nodes had been measured by means of an optical interference stripes method[4] just as in the preceding case. Magnetization in a vibration state was measured by the ballistic galvano method.

III. Results and discussions

1. Dependence of Q^{-1} upon magnetization and vibration stress

Q^{-1} was measured under different resonance frequencies and different grades of vibration stress over the range of magnetization from the saturated to the residual state. The largest vibration stress σ used stands 3.4, 16.4, 32.7 and 49.0 k dyne/cm^2, and resonance frequency $f=0.64$, 1.78, 3.48 and 5.80 kHz. In Fig. 1, Q^{-1} was shown as a function of the effective magnetic field H_{eff}, at $\sigma=16.4$ k dyne/cm^2. As is clear in the figure, Q^{-1}, independent of the value of f, increases with decreasing H_{eff} and shows a maximum. In a strong magnetic field, Q^{-1} becomes large and its maximum appears in a higher H_{eff} with increasing f. Here, attention should be given to the fact that the measured Q^{-1} includes hysteresis loss Q_h^{-1}, macro eddy current loss Q_a^{-1}, micro eddy current loss Q_i^{-1} and mechanical loss Q_M^{-1}. Fig. 2 shows the curves of Q^{-1} vs H_{eff}, with various σ at $f=0.64$ kHz. As is clear on the curves, the Q^{-1}-H curve little varies with σ in a magnetically saturated state. The maximum value in Q^{-1} grows large with increasing σ.

(3) R. Ocschenfelt, Z. Phys., **143** (1955), 357.

(4) S. Edelman, E. Jones and E.R. Smith, J. Acoust. Soc. Amer., **27** (1955), 728.

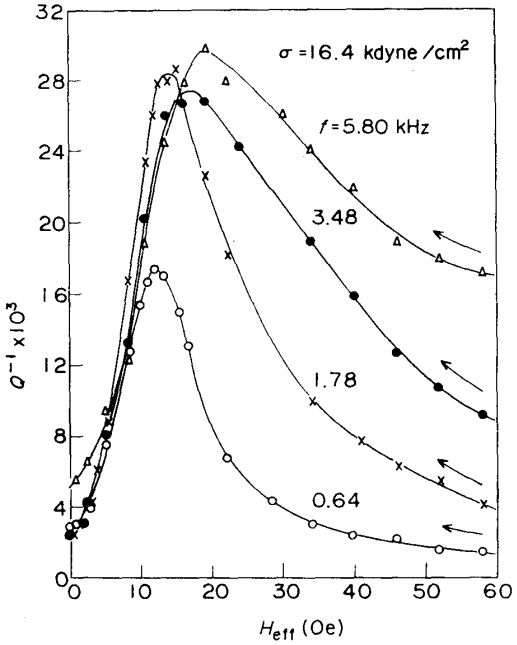

Fig. 1. Magnetomechanical internal friction Q^{-1} as dependent on demagnetizing effective field H_{eff} and resonance frequency f.

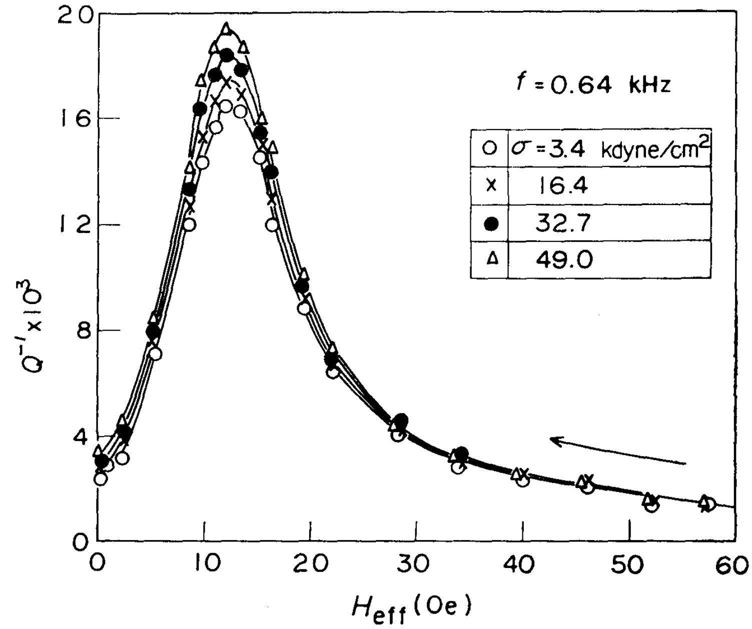

Fig. 2. Magnetomechanical internal friction Q^{-1} as dependent on demagnetizing effective field H_{eff} and dynamic stress σ.

2. Hysteresis curves of Q^{-1}

The hysteresis loop of Q^{-1} was measured in a magnetically saturated state. Fig. 3 shows the field dependence of Q^{-1} in the first quadrant at σ=16.4 k dyne/cm² and f=0.64 kHz. As is clear in the figure, Q^{-1}-H_{eff} curves are similar in both magnetization and demagnetization, but clearly present a phenomenon of

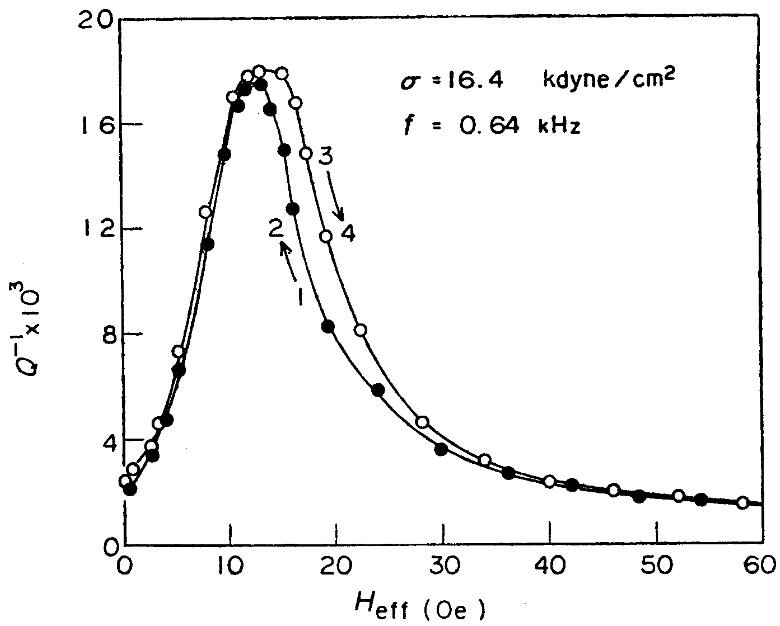

Fig. 3. Hysteresis curve of magnetomechanical internal friction Q^{-1} as plotted against magnetic field H_{eff}.

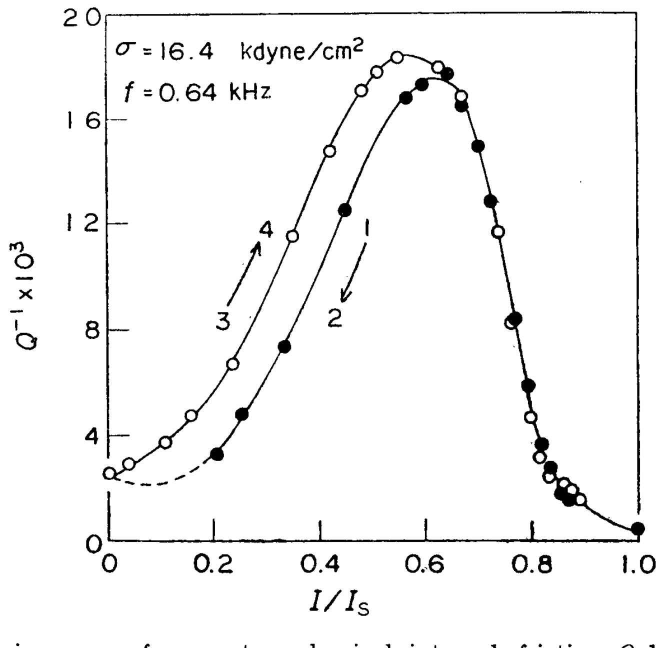

Fig. 4. Hysteresis curve of magnetomechanical internal friction Q^{-1} as a function of magnetization I/I_s.

hysteresis. Q^{-1} in Fig. **3** can be expressed as a function of magnetization I/I_s as in Fig. **4**, which evidently shows that the hysteresis curve of $Q^{-1}-I/I_s$ describes a loop at $I/I_s=0\sim0.6$, and is almost reversible at $I/I_s>0.6$. The residual magnetization is $I/I_s=0.2$, and the coercive force $H_c=0.15$ Oe.

3. Separation of hysteresis loss Q_h^{-1}

Q^{-1}, obtainable as already shown, will be given as:

$$Q^{-1} = Q_h^{-1} + Q_a^{-1} + Q_i^{-1} + Q_M^{-1} \tag{3}$$

Q^{-1} as a function of vibration stress σ at constant I/I_s and constant f can be schematically shown as in Fig. 5. In the range where σ is small, only Q_h^{-1} depends on σ, so the value of Q^{-1}, extraporated on $\sigma=0$, stands $Q_a^{-1}+Q_i^{-1}+Q_M^{-1}$,

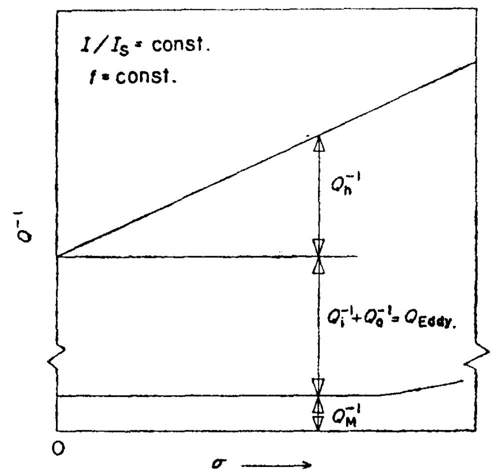

Fig. 5. Schematiec representation of relation between various losses Q^{-1} and stress σ.

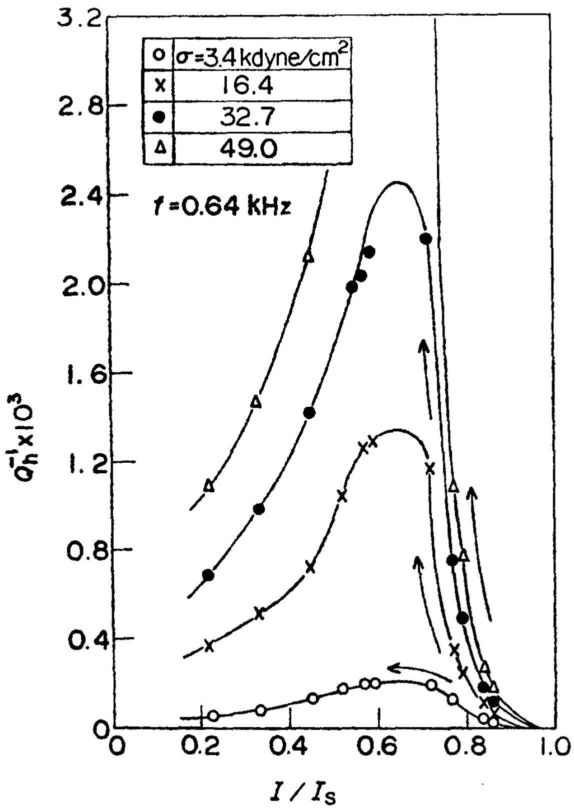

Fig. 6. Hysteresis loss Q_h^{-1} as dependent on magnetization I/I_s and dynamic stress σ.

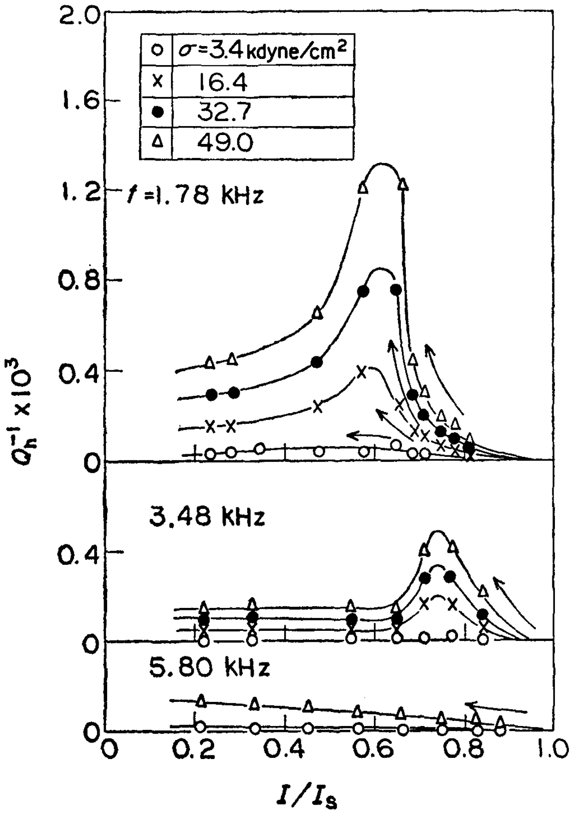

Fig. 7. Hysteresis loss Q_h^{-1} as dependent on magnetization I/I_s and dynamic stress σ.

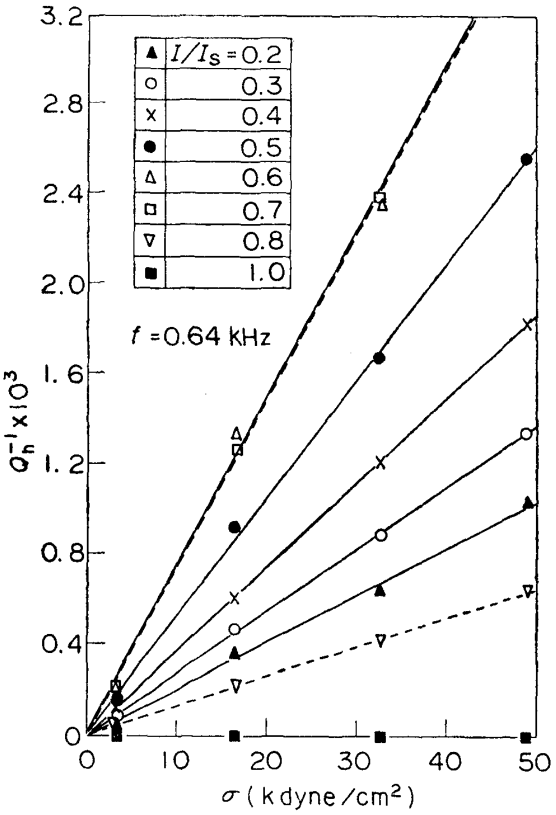

Fig. 8. Hysteresis loss Q_h^{-1} as dependent on dynamic stress σ and magnetization I/I_s.

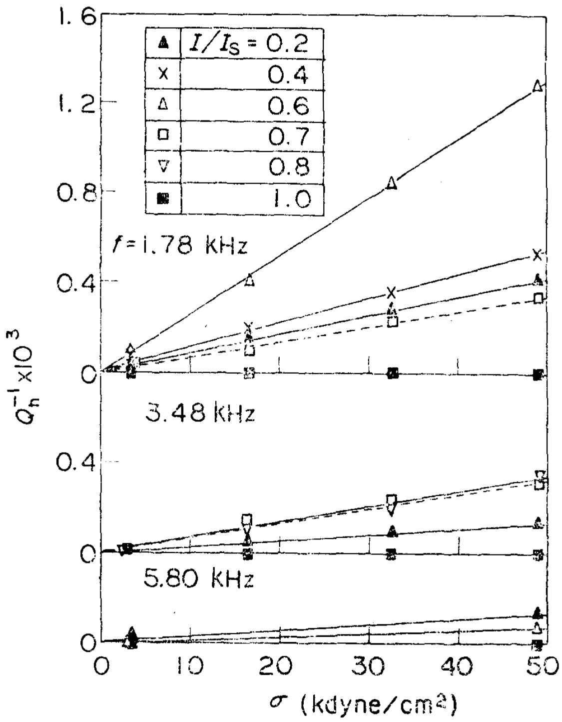

Fig. 9. Hysteresis loss Q_h^{-1} as dependent on dynamic stress σ and magnetization I/I_s.

and thus Q_h^{-1} can be obtained. This attempt may be the first to separate Q_h^{-1} from the dependence of Q^{-1} on σ.

Fig. 6 shows the magnetization dependence of Q_h^{-1}, at f=0.64 kHz with varieties of stress, where Q_h^{-1} is very small covering only about 7% of Q^{-1}. As is clear from the graph, with weakening magnetization, Q_h^{-1} sharply increases to show a maximum at about I/I_s=0.60; and as σ grows large the maximum of Q_h^{-1} goes up high. These Q_h^{-1} with various f were graphed in Fig. 7, which evidently shows that as f increases the maximum value in Q_h^{-1} decreases and finally shows no sign of it at f=5.80 kHz. The stress dependence of Q_h^{-1} at constant f with various cases of magnetization are shown in Figs. 8 and 9. Fig. 8 denoting the results at f= 0.64 kHz, cearly shows that Q_h^{-1} at I/I_s=1.0, almost independent of σ, stands 0, but at I/I_s=0.8 it increases in proportion to σ, with the proportional constant showing a peak at I/I_s=0.7~0.6. As evidently shown in Fig. 9, the dependence of Q_h^{-1} on σ decreases with increasing f.

4. Dependence of Q_h^{-1} on f

Q_h^{-1} at constant I/I_s was got as a function of f, and the results at σ=16.4 k dyne/cm² are graphed in Fig. 10, which clearly shows that Q_h^{-1} stands almost 0 where f is high, but as f is decreased, Q_h^{-1} turns to follow a sharp upward curve from about 3.0 kHz. Also Q_h^{-1} depends on the state of magnetic domain distribution and shows the largest at I/I_s=0.6.

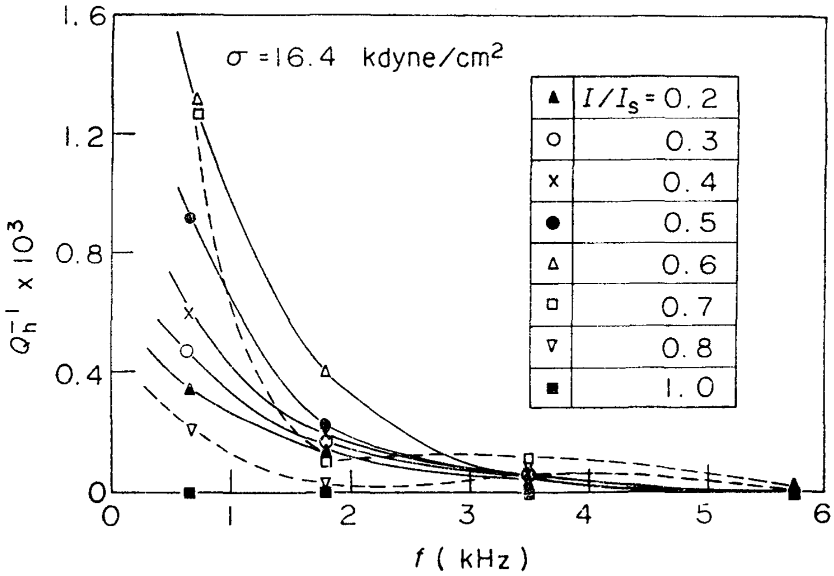

Fig. 10. Hysteresis loss Q_i^{-1} as dependent on resonance frequency f and magnetization I/I_s.

Table 1. Dependence of internal friction on frequency f and stress (see reference (5)).

Kind of internal friction	Symbol	Dependence of Q^{-1} on f	Dependence of Q^{-1} on σ
Macro eddy currents	Q_a^{-1}	$\propto f$ (low f) $\propto f^{1/2}$ (high f)	Independent
Micro eddy currents	Q_i^{-1}	$\propto f$	Independent
Magnetomechanical hysteresis	Q_h^{-1}	Independent	$\propto \sigma$

Hitherto the relations of Q_a^{-1}, Q_i^{-1} and Q_h^{-1} to f and σ have been shown as in Table 1[(5)], which indicates independence of Q_h^{-1} on f. However, as shown in Fig. 10, Q_h^{-1} in the current experiments sharply decreases with increasing f. Here, the discrepancy of these results should be studied in detail. Q_h^{-1} in Table 1 is the result in which no consideration has been given to the reversible displacement of non–180° magnetic domain wall which will surely take place when external stress is drawn on periodically. On the contrary, the present authors' measurements can be considered to have been made in the range of reversible magnetic domain rotation and 180° magnetic domain wall displacement. Further, the measured Q_h^{-1} is not regarded the only one due to the non–180° magnetic domain wall displacement caused in the process of magnetization. On the other hand, Q_h^{-1} may also be due to the magnetic domain wall displacement induced from periodical vibration stress–a "*shake*" of magnetic domain. That is, at a high f the domain displacement corresponding to vibration stress does not occur quickly, and at a low f non–180° magnetic domain

(5) R.M. Bozorth, *Ferromagnetism*, D. von Nostrand Co., (1951), 709.

wall displacement is induced periodically. That a part of Q_h^{-1} is due to the *"shake"* of magnetic domain induced by vibration stress does not contradict the results in the preceding report,[2] in which frequency dependence was explained on the assumption that the ΔE effect contains the effects of both magnetostriction and vibration. It may be considered that the new explanation rather suggests the existence of the effect ($d\varepsilon_f/d\sigma$ —— the second term of Eq. (1)).

5. Loss by eddy currents

The remainder of Q^{-1} with Q_h^{-1} subtracted comes as Q_a^{-1}, Q_i^{-1} and Q_M^{-1}. And Q_M^{-1}, independent on I/I_s, is extremely small compared with other losses. So, in disregard of Q_M^{-1}, $Q_a^{-1}+Q_i^{-1}$ can be graphed as a function of I/I_s as in Fig. 11. As is clear from the graph, $Q_a^{-1}+Q_i^{-1}$, when I/I_s is removed from a magnetically saturated state, suddenly increases and shows a maximum at $I/I_s=0.8\sim0.6$. This $Q_a^{-1}+Q_i^{-1}$, contrary to Q_h^{-1}, grows large as f rises high.

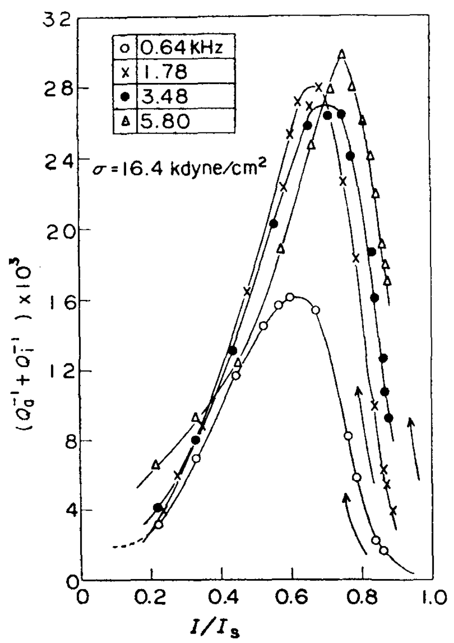

Fig. 11. Eddy current loss $Q_a^{-1}+Q_i^{-1}$ as dependent on magnetization I/I_s and resonance frequency f.

Summary

The dependence of internal friction Q^{-1} upon magnetic field H was measured by means of the elctrostatic driving method for nickel annealed at 1000°C for 10 hr in vacuum. The results obtained include:

(1) According as H decreases from a magnetically saturated state, Q^{-1} suddenly increases from about $H=30$ Oe and forms a maximum near $H=15$ Oe.

(2) The dynamic stress was measured by the optical interference stripes

method, and the hysteresis loss Q_h^{-1} has been successfully separated from the whole loss Q^{-1}.

(3) Q_h^{-1}, when shown as a function of magnetization I/I_s falls off lower with increasing driving frequency f, and finally vanishes at $f=5.8$ kHz.

(4) Q_h^{-1} emerges from a reversible displacement of non—180° magnetic domain wall due to periodical dynamic stress. The fact suggests the existence of the vibration effect included in the dynamic ΔE effect.

Acknowledgement

The authors would like to express their sincere thanks to Asst. Prof. Ichiro Oguma for the substantial help and assistance.